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I, JULIE BILLINGSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. PS 3228 for a patent by THORLOCK INTERNATIONAL LIMITED as filed on 26 June 2002.

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PROVISIONAL SPECIFICATION

Invention Title: Large Volume Scanner For Nuclear Quadrupole Resonance Measurements (#14)

The invention is described in the following statement:

"Large volume scanner for nuclear quadrupole resonance measurements"

Field of the Invention

This invention relates to, but is not limited to, the detection of explosives and narcotics located within mail, airport luggage and other packages using nuclear quadrupole resonance (NQR). More specifically it relates to a practical system for use in NQR scanning.

Throughout the specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

Background Art

The following discussion of the background art is intended to facilitate an understanding of the present invention only. It should be appreciated that the discussion is not an acknowledgement or admission that any of the material referred to is or was part of the common general knowledge in Australia as at the priority date of the application.

In the prior art there exist many different combinations for achieving an NQR scanner, however, careful selection of the required components is required to achieve a practical scanner to make it function successfully. There are several key features to an NQR scanner which are required to make a successful device. These include:

Coil and Shield:

For NQR scanning, the coil used should be able to produce a reasonably uniform magnetic field over the entire scan volume. If the field is weak at any point within

its volume the substance of interest will not be excited in the part of the coil and consequently the subtance will not be detected. A further requirement is that the coil must have a high Q to detect the typical small signals from NQR samples inside large volumes. Another requirement is that the size of the electric field shoud be limited and contained so that it interferes with the scan item of interest, if at all, to the smallest possible extent.

Spiral coils cannot be used for large volume applications because they firstly do not produce a reasonably uniform field over a particular volume. Secondly, the inductance values of spiral coils are very large, which means that they are difficult to resonate at high NQR frequencies. Thirdly, as they cannot contain the magnetic field they produce like solenoids, some field is wasted irradiating into a non usable volume.

The use of spiral coils can be improved by using two coils and passing the scan item between these coils however once again the inductance is very large and it is difficult to tune the coil. Spiral coils also suffer from a low Q, which would limit the detection sensitivity.

Solenoidal coils can not be used as the inductance from these coils is also very large, which also means that these coils are difficult to tune at the higher end of the NQR frequencies. Solenoidal coils also become limited in Q as the number of turns becomes higher. It is possible to scan an item with an array of coils where the scan item passes between the two arrays of coils, however, such a system suffers from two problems: (i) a non uniform field, and (ii) individual coils affect each other decreasing their Q and thus sensitivity.

For a practical NQR system, the shield design needs to be such that it fully encloses the coil leaving at least one opening for a scan item to pass into the volume being scanned. The shield design also needs to stop external interference from entering the scan volume and stop EM emissions from escaping from the coil volume.

Conveyor belt:

An NQR system requires a conveyor belt to automatically transport the scan item to a position close to the centre of the coil. The conveyor belt needs to be able to automatically stop the scan item such that it can be scanned. The time to move the bag in and out ideally is needed to be less than 2 seconds. X-ray airport luggage scanners typically have belt speeds which are too slow and also do not stop within the scan volume unless interupted by the operator.

Tuning:

Once the bag is within the scan volume, a tuning sequence is required. This tuning sequence is required to determine if the introduction of the scan item into the scan volume has altered the resonant frequency of the device. To achieve the re-tuning of the device, switches need to be activated to switch capacitors in or out of the circuit. Variable capacitors cannot be used for this purpose because they are large and slow in operation and have a very low Q factor.

Q Switch:

A Q switch, as the name implies, changes the Q at some point during the operation of the NQR scanner. As the signals are measured typically in a high Q state, ringing, which is ever present on a coil after a transmit pulse, needs to be removed. This can be achieved by switching the Q to a lower value just after the transmit pulse has finished and thus reduce the ring down time to a small value and allow measurement of the NQR signal.

Various methods have been used as Q switches including simple resistive Q damping, phase reversal damping, capacitive or inductive damping and transformer induced damping. All of these methods have some merit in removing the ringing of the coil.

Excitation:

To detect an NQR substance, an RF source is required to generate a signal at the NQR frequency of interest. A programmable device is required to take the signal

from the RF source and convert it into a pulse sequence which can be sent to the coil to irradiate the scan item in a pulsed magnetic field. This programmable device includes the ability to produce pulses of any duration and any phase.

The pulse sequence used must be able to at least cancel some magnetoacoustic ringing, mitigate temperature effects and not be so long as to make the measurement process too long for practical scanning. This limits the pulse sequences that can be used to those that do some phase cycling so that the NQR signals add coherently and the interfering signals add incoherently. The use of such pulse sequences also overcomes temperature effects.

Measurement:

The measurement process begins by detecting and amplifying the signal and then sending the received signal from the coil to a mixer. The mixer turns the signal into a quadrature signal allowing $\sqrt{2}$ improvement in signal-to-noise (SNR). The two quadrature signals are sent to an analogue to digital converter (ADC). Here the signal is averaged after each pulse until the pulse sequence is finished. After the averaging process is completed the result is sent to a computer to be further processed by filtering, fast fourier transform, & cross correlation methods to separate out the phase and amplitude of the signal. The process ends with the measured amplitude and/or phase being compared to a known range or against a threshold.

Detection:

If the one or more of the measured signal's parameters do lie within a measured range or above a threshold, then the operator is alerted by an audible alarm or visible display.

Disclosure of the Invention

It is an object of the present invention to provide for a practical NQR detector for scanning for the presence of illicit substances and a method for such scanning.

In accordance with a first aspect of the present invention there is an NQR scanner comprising:

(i) a multiple loop coil,
(ii) inner and outer shields,
(iii) waveguides,
(iv) conveyor belt subsystem,
(v) tuning subsystem,
(vi) at least one temperature probe for sensing temperature,
(vii) programmable RF source,
(viii) programmable gate controller for generating pulses,
(ix) high power RF transmit amplifier,
(x) semiconductor based Q switch,
(xi) pulse sequence able to combat magnetoacoustic ringing and temperature effects,
(xii) back-to-back protection diodes,
(xiii) transimpedance amplifier or high impedance amplifier,
(xiv) analogue to digital converter,
(xv) accumulator or digital signal processor,
(xvi) computer,
(xvii) alarm or visual display of the result;

which together produce an NQR scanner suitable for scanning items intended to pass through a portal from one location to another.

In accordance with a second aspect of the present invention, there is provided an NQR scanner comprising:

(xviii) a sheet single turn solenoid,
(xix) inner and outer shields,
(xx) waveguides,
(xxi) conveyor belt subsystem,
(xxii) tuning subsystem,
(xxiii) at least one temperature probe for sensing temperature,
(xxiv) programmable RF source,

(xxv) programmable gate controller for generating pulses,
(xxvi) high power RF transmit amplifier,
(xxvii) semiconductor based Q switch,
(xxviii) pulse sequence able to combat magnetoacoustic ringing and temperature effects,
(xxix) back-to-back protection diodes,
(xxx) transimpedance amplifier or high impedance amplifier,
(xxxi) analogue to digital converter,
(xxxii) accumulator or digital signal processor,
(xxxiii) computer,
(xxxiv) alarm or visual display of the result;

which together produce an NQR scanner suitable for scanning items intended to pass through a portal from one location to another.

Preferably, in either aspect, the NQR scanner includes doors to prevent the escape of RF interference and prevent RF noise entering the scan volume.
In addition, or alternatively, to the doors, the NQR scanner preferably includes RF curtains to prevent the escape of RF interference and prevent RF noise from entering the scan volume.

In accordance with a third aspect of the present invention, there is provided a method for scanning for the presence of illicit substances in items, comprising: sequentially effecting the function of each of the elements of the NQR scanner defined in either of the preceding aspects of the present invention to scan for the presence of illicit substances in items.

Brief Description of the Drawings

Figure 1 shows a diagram of the components of a practical NQR scanner in accordance with the first embodiment.

Figure 2 shows a side of the machine with the doors attached.

Figure 3 shows a side view of the multiple loop coil within the shield.

Best Mode(s) for Carrying Out the Invention

The best mode for carrying out the invention will now be described with reference to three specific embodiments of an NQR scanner as illustrated in Figures 1 and 3. In each of the following embodiments, the particular combination of the specific elements described has enabled the construction of a practical NQR scanner capable of detecting illicit substances. This embodiment of a NQR scanner has been arrived at after much experimentation.

The first embodiment of the best mode is directed towards an NQR scanner, and comprises specific elements described below.

Coil and shield:

As stated in the preceding description, spiral, multi turn solenoids, and nearly every other coil is not suitable for use in a practical NQR scanner. This leaves few choices for practical NQR scanning. One choice is to use a multiple loop coil 41, which consists of multiple loops connected in parallel. This design has the following desirable properties:

(a) Reasonably uniform magnetic field.
(b) High Q.
(c) The electric field can be confined to a small volume mostly isolated away from the sample.

Most other coil designs are deficient in one or more properties and are not suitable for use as a large volume scanner.

The shield design 42 is required to be made from sheet metal and be spaced far enough from the coil such that it doesn't substantially degrade the Q of the coil. The closer the shield is to the coil, the greater the increase in resistance and loss of inductance, resulting in lower Q. By moving the shield far enough away from

the coil, the Q limits towards a maximum value. There are obviously practical limits to how far the shield can be moved away from the coil, hence a reasonable spacing is X/2 between the coil and shield, where X is the coil dimension in that direction. The coil and waveguide separation is also X/2. Any closer than this also substantially degrades the Q of the system. The waveguide can be made of any length provided cancellation of the external noise occurs. The best length for the waveguides has been found to be X for NQR frequencies.

A second outer shield (not shown in Fig.3) has also been added to give extra isolation from the surrounding RF environment and to further prevent the escape of RF signals.

Curtains 43 are added to prevent escape of RF signals from the system and stop external noise from entering the coil. The curtains are vertically flapping, pieces of copper strips with rubber stuck onto either side, and are located at the extremity of the waveguides and near the middle of the waveguides as shown in Fig.3.

Conveyor Belt:

The conveyor belt moves the object to be scanned into position and then passes it through to the exit after the scan has taken place. The important point with respect to moving the bag is fully stopping the bag in the coil. By ensuring the bag is no longer moving when it is inside the coil, correlated noise such as magnetoacoustic ringing can be at least partially cancelled.

Tuning:

After moving the bag into the coil, the resonant frequency can be altered such that the coil system is no longer at the intended frequency. To correct this problem the coil is re-tuned by adding in or subtracting out capacitance out of the resonant circuit. This addition or subtraction is achieved by switching relays 7.

The large bar switch 6 allows the switching into the circuit of a large capacitance 5 required to shift the resonant frequency to and from a high or low frequency. The use of this large bar switch avoids injecting a large equivalent series resistance and thus maintains high Q.

Excitation:

To generate a pulse sequence to transmit to the coil, the following method is used. First, the ambient temperature is sensed by one or more probes 19. The temperature or temperatures are converted into a frequency for each substance to be scanned by looking up a conversion table in the computers 20 memory or calculating the frequency corresponding to the temperature. The signal close to the calculated frequency from an RF source is sent to the programmable gate controller (PGC) 2. The PGC 2 has stored within its memory a pulse sequence for each substance. Every pulse sequence needs to be able to combat the effects of magnetoacoustic ringing. This is usually achieved by using some form of phase cycling. The pulse sequence must also combat the effects of temperature variations, fortunately the same sequences that combat the magnetoacoustic ringing also combat temperature effects.

After the pulse sequence has been created it is sent to a high power RF amplifier 3 and amplified to the kW level and transmitted to the coil 9. This signal creates a field inside the coil between 1-2 Gauss to illicit a response signal from the NQR substance but be low enough such that it doesn't cause damage to electronic items. In response, if an NQR sample is present it will be excited and induce a small voltage signal on the coil.

Q Switch:

In order to detect the small NQR signal after the transmit pulse has been removed, a Q switch 4 is used. The Q switch 4 causes a rapid ring down of the coil 9 and allows the small NQR signal to be recorded before it decays to a level

which is too low to measure. In this embodiment the use of triacs have been found to be an effective method to remove the ringing energy from the coil.

The circuit for the Q switch 4 in the best mode consists simply of a triac connected in parallel across the coil.

Protection Diodes:

To protect the sensitive electronics on the receive side of the system, back-to-back blocking diodes 10 are used. During transmit these isolate the receive system from the high power signal transmitted to the coil. After the transmit pulse has been removed and most of the signal has been conducted to ground, the blocking diodes 10 are switched out of the circuit allowing the signal to be transmitted to the receive part of the system.

Measurement:

After the diodes have been switched out of the circuit and a suitable time delay has passed, the measurement process begins by sending the received signal from the coil to an amplification unit 11, 12. Low frequency NQR signals are amplified by a cold damped amplifier 11 consisting of a matching section and an amplifier. High frequency NQR signals are amplified by a high impedance amplifier 12. The matching section ensures maximum transfer efficiency of the signal. The use of two different amplifiers for each different frequency range has been shown to have superior qualities over other amplification techniques. The switches 13 and 14 select which path the signal will follow. After amplification it is mixed 15 with the PGC reference signal 2 forming a quadrature signal 16,17. These two channels are sent to the ADC 18 for conversion into digital signals. Here the signal is averaged after each pulse until the pulse sequence is finished. After the averaging process is completed the result is sent to a computer to be filtered and fast fourier transformed to separate out the phase and amplitude of the signal. The process ends with the measured amplitude and/or phase being compared to a known range or against a threshold.

Detection Result:

If the one or more of the measured signal's parameters do lie within a measured range or above a threshold, then the operator is alerted by an audible alarm or visible display unit 21.

The second embodiment is substantially the same as the first, except that the coil used is a single turn sheet coil. The single turn sheet coil has a high Q, substantially uniform magnetic field and the electric field is confined to a small area away from the coil.

The third embodiment is substantially the same as the first or second embodiments, except that the waveguides are either replaced by doors or doors are inserted into the system, preferably between the main part of the shield and the waveguides. Under this embodiment the curtain may be removed as it will be redundant. Figure 2 shows a side view of the NQR scanner with doors 30 attached between the main part of the shield 32 and the waveguides 31.

When using the doors without waveguides, the overall machine can be shortened allowing the machine to fit in tight spaces, whereas other devices such as X-ray machines cannot. When the doors 30 are open (as shown in Fig.2), a bag is moved into position and then the doors 30 are shut. This prevents the escape of RF signals from the machine and stops RF noise from getting into the scan volume. Once the scan process is finished the doors 30 are opened and the bag is free to move forward, exiting the machine.

It should be appreciated that the scope of the present invention is not limited to the particular embodiments described herein, and that minor changes or variations to the elements may be made that do not depart from the spirit of the invention and thus remain within its scope.

Dated this 26th day of June 2002.

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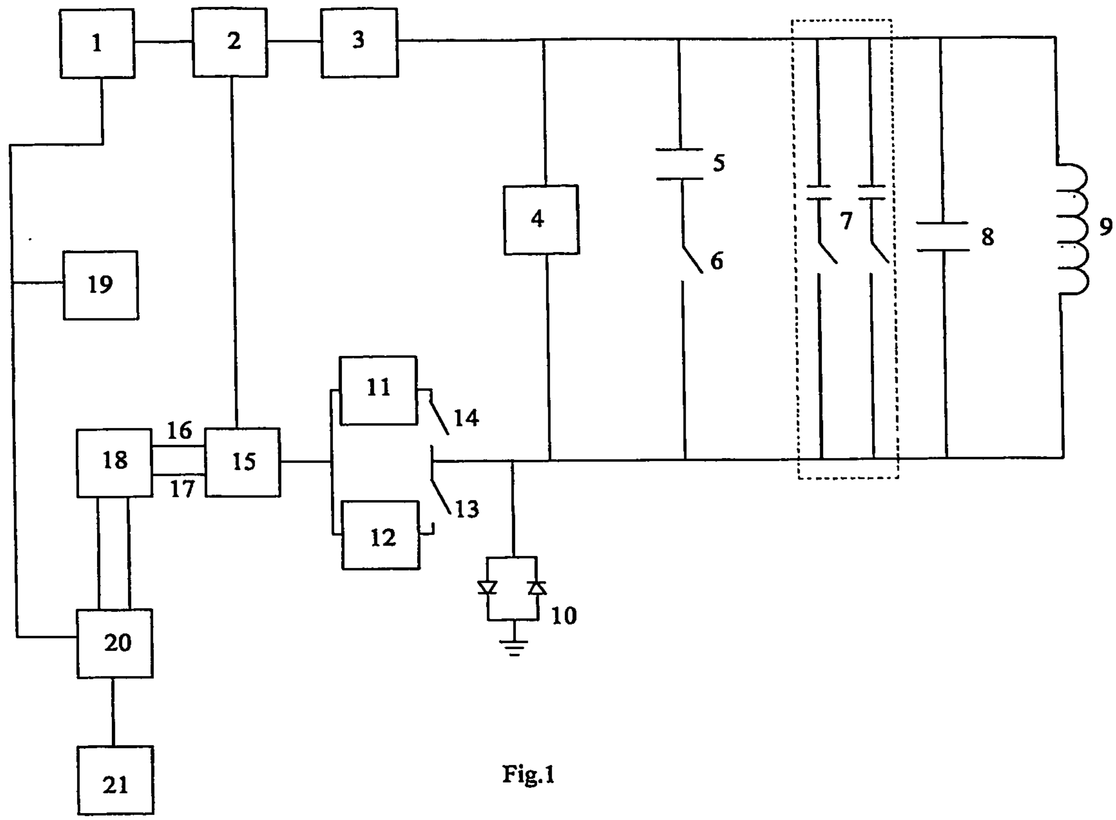

Fig.1

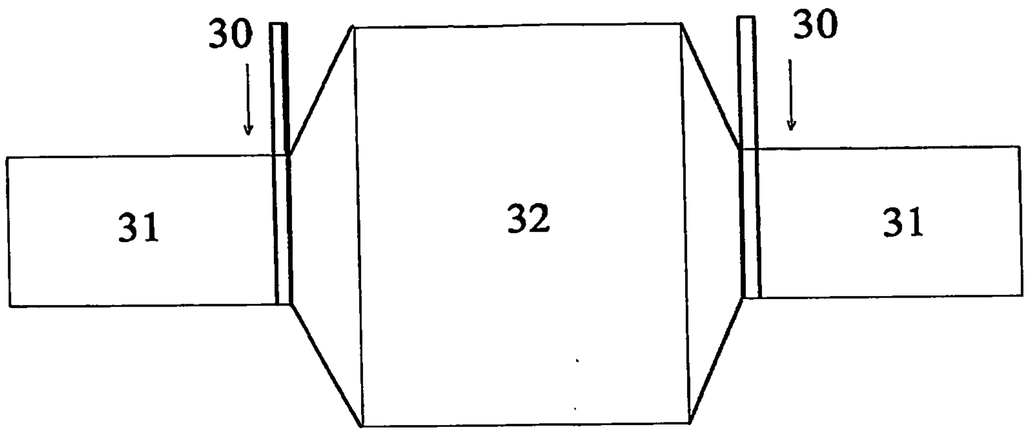

Fig.2

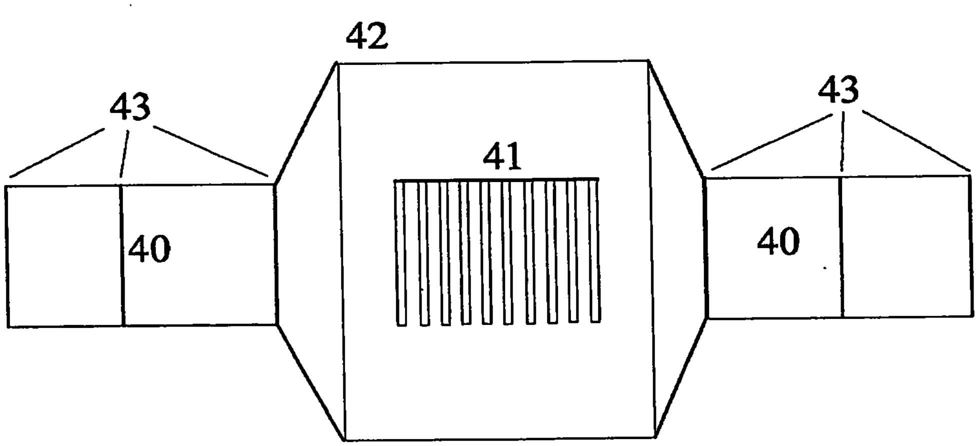

Fig.3